SECTION B - HYDRAULICS

Contents

SECTION B - HYDRAULICS

Figures

SECTION B - HYDRAULICS

I. INTRODUCTION

Selecting the proper gate and outlet conduit size, in many cases, will be based on a head that is less than that with a full reservoir. This results when the water needs are less at the beginning of a season at the time the reservoir is full. As the reservoir level drops, the water requirements can increase. Obviously the gate and conduit system should be designed for this critical discharge-head relation. For less critical conditions, the system would be operated with the gate partially closed.

Less obvious, however, is the possibility that the system may be operated with full head at full gate opening exceeding design discharge. This condition will be the critical one for certain outlet structures and can materially add to the cost of the system. Whether or not the outlet is sized for design discharge or maximum discharge requires judgment with the greater capacity recommended.

The minimum diameter of the outlet conduit may be set by Service and individual state requirements and varies from no restriction to 30 inches. An outlet conduit diameter of not less than 6 inches, preferably 10 inches, is recommended. Minimum diameter may also be established by the length of time it takes to dewater a reservoir by gravity flow. Recommended flow duration at full gate opening should not exceed 10 days.

Factors that determine the flow in a gated outlet include variables as the size, shape and type of control gate and conduit used, the slope, length and roughness of the conduit, the inlet and outlet conditions and the head on the system. The combined effect of any of these factors may determine the flow in the system.

The nomographs and charts in this section were prepared to provide the engineer with the hydraulic relationships commonly encountered in the design of small gated outlets.

The discussion of "Location of Control", "Full Pipe Flow" and "Partial Pipe Flow" is a simplification of actual conditions, in some cases to a point that can be misleading to the unwary.

Many problems are associated with the calculation of water surface profiles in a circular cross-section on a fixed grade line. The major ones are:

(1) The effect of air entrainment and consequent bulking of the flow,

(2) Determination of energy loss for the bulked flow and its variable "n" value,

(3) Effect of pipe joints, elbows, gates, etc.

(4) Geometry of the inlet for both partial and fully open conditions as well as accuracy in evaluating the tailwater elevation,

(5) The certainty that the conduit, on a compressible foundation, is subject to joint rotation and elongation that make the grade line of the conduit indeterminate.

The rest of the hydraulics section should be read keeping in mind that inlet control means partial pipe flow and outlet control means full pipe flow.

II. LOCATION OF CONTROL

Location of the control from the hydraulic standpoint dictates whether the conduit flows full or partly full and thereby establishes the head-discharge relationship. Slope of the pipe and the tailwater level are factors that determine location of the control. The slope may be mild or steep, that is, it may be flatter or steeper than the slope at which a given discharge will just support flow at a critical stage. For either a mild or steep slope, the control may shift from inlet to outlet depending on the head, tailwater, and gate opening.

For partial pipe flow, the control is normally at the inlet where orifice conditions control the discharge. For full pipe flow the control is at the outlet, and the total head on the system is determined by the elevation of the tailwater. In the case of free outfall at the outlet, the tailwater elevation is considered the center of the pipe outlet.

III. FULL PIPE FLOW

Full pipe flow usually occurs in long conduits with a mild or flat slope or where the outlet is submerged. The depth of water at the entrance must be greater than 1.2 times the inside diameter of the pipe to produce full pipe flow. Partial pipe flow may occur with the inlet submerged if the slope is steep or if the pipe is short enough so that a hydraulic jump does not occur in the length of the pipe and air is admitted through the outlet or by means of a vent. Full pipe flow conditions control for nearly all gate openings if the conduit is on a mild slope.

IV. PARTIAL PIPE FLOW

Partial pipe flow usually occurs in short conduits with sharp corners or inward projecting entrance and low heads. Partial pipe flow may also occur where the conduit is on a steep slope with partial gate openings and free outfall. In this case the inlet acts as an orifice to control the flow.

The inlet must be vented to have orifice control. The vent may be a vent-pipe or the airspace maintained above the water surface during partial pipe flow with free outfall and air admitted from the outlet.

If the conduit flows full at any point and the inlet is not vented, the high velocity flow will carry away entrapped air. The pressure in the pipe can then drop below atmospheric pressure and cause operation problems and structural damage.

V. CAVITATION

Localized constrictions, surface irregularities, and abrupt changes in alignment provide conditions for potential structural damage. This damage is caused by the successive formation and collapse of vapor pockets in low pressure areas associated with high velocity flow. The collapse of vapor pockets cause implosions that result in pitting of the concrete or the metal conduit surface. The pitting then accelerates the effect of cavitation by intensifying the negative pressures.

Several measures will reduce the potential for cavitation: streamlining of entrances and slots; increasing the cross-sectional area; or, introducing air by venting to the low pressure area.

Venting the conduit just downstream of the gate is recommended. Further discussion of vent pipes is presented in Section C, Inlets.

Conduits carrying flow with velocities in excess of 25 fps should be studied for cavitation potential.

VI. USE OF CHARTS AND GRAPHS

It should be recognized that these charts and graphs were developed for average conditions. Some of the relationships were derived from model studies. The curves or values may be an average of the results of these studies. Any deviation from the condition of the study could change the results; however, these relationships will give usable answers for most design problems in small gated outlets. If exact values are required for a specific structure, detailed computations will be necessary to evaluate the exact conditions and requirements for that structure.

A. Full Pipe Flow With Gate Fully Open

1. Figures B-1 through B-4

Figures B-1 through B-4 were developed to quickly determine the pipe size and flow velocity for a given height of dam and discharge. THESE CHARTS APPLY TO FULL RESERVOIR CONDITIONS. For lower stages, chart discharges will be high and Figures B-6 through B-10 should be used. Each chart gives the relationships for a different conduit roughness (Manning's "n" value). They apply for an entrance condition of a fully open gate with square corners and a single miter bend. Energy loss is based on a pipe length for an embankment slope of 3:1 upstream and 2:1 downstream. The top width of the embankment is $2\sqrt{H}+5$ where H is the vertical distance from the spillway crest to gate centerline. A combined headloss coefficient of 1.24 was used for the entrance and elbow. The losses for these conditions are considered to be average for small dams with the head range shown on the charts.

The charts are entered with known values of head and discharge. The pipe diameter and velocity of flow are determined from the curves. If the point falls between two diameter lines, the larger diameter must be used to obtain the given discharge and velocity can be determined directly.

The most common pipe sizes for concrete and corrugated metal pipe were used in the construction of these charts. Relationships for other pipe sizes may be determined by interpolation.

2. Figures B-5 through B-10

Figures B-5 through B-10 give the relationships for full pipe flow with various entrance conditions and variable pipe lengths. THEY ARE FOR USE IN HYDRAULIC ANALYSIS WHERE THE RESERVOIR IS LESS THAN FULL OR WHERE THE PIPELINE EXTENDS BEYOND THE TOE OF THE DAM. They are also valid for the full reservoir stage although additional computation is required to find flow velocity. Figure B-5 is used to determine the loss coefficient (K_e) for various entrance types. Figures B-6 through B-10 present the relationships of head, length of pipe, and discharge for various entrance loss coefficients in nomograph form. These nomographs have been developed for four pipe roughness factors (Manning's "n" values) that apply to most installations. The difference between Figures B-7 and B-8 is the head range. Example solutions are shown on the nomographs.

Note that the entrance headloss coefficients (K_e) on Figure B-5 represent the loss for the entrance type, including any bends or corners connected with the inlet, as shown by each illustration. Headloss coefficients for partial gate openings are not included on this chart but may be obtained from Figure B-12.

B. Partial Gate Opening

1. Partial Pipe Flow, Figure B-11

Figure B-11 was developed to determine the flow characteristics at partial gate openings with partial pipe flow. This nomograph gives the relationships for orifice control at the inlet. However, partial pipe flow should be compared with the full pipe flow condition to determine which controls the discharge.

To determine if full or partial pipe flow controls, enter Figure B-11 with the given head, gate opening and gate size. The resulting discharge is then noted. For partial pipe flow to exist, this discharge must be less than the normal full pipe flow discharge that would occur with the particular pipe size and slope with free discharge. Calculations for this condition are described in Section 2 below.

2. Full Pipe Flow, Figures B-12 through B-17

The normal discharge for full pipe flow for a given pipe diameter and slope can be determined from Figures B-14 through B-17 (ES-54). If the full pipe flow determined from the above figures is less than the discharge as determined from Figure B-11, the conduit is flowing full and calculations must be made to determine the correct discharge.

The hydraulics of full pipe flow are based on these fundamental relationships:

a. $Q = AV$

b. $H = \frac{V^2}{2g} (1 + K_e + K_b + K_p \ell)$

From these the following equations are derived:

c. $C = \frac{1}{\sqrt{1 + K_e + K_b + K_p \ell}} = \frac{1}{\sqrt{\Sigma K}}$

d. $Q = 6.30 \, CD^2 \, H^{1/2}$

where

Q = discharge in cfs
D = inside diameter of conduit in feet
H = total head in feet (upstream water surface to tailwater surface or center of pipe at outlet for free outfall)
A = flow area, square feet
V = flow velocity, feet per second
ΣK = summation of headloss coefficients including K_e, entrance loss, K_g, gate loss, K_b, bend loss, $K_p \ell$, pipe friction loss, K_o, exit loss, and any other losses involved.

Headloss coefficients are related to the velocity in the conduit at full pipe flow. Note that the addition of a headloss coefficient for partial gate openings (K_g) will modify the headloss coefficient for the entrance (K_e) as shown in Figure B-5. Subtracting 0.5 from the value of K_e for the fully open gate results in a bend loss (K_b). Values for K_g and K_b replace the combined loss K_e used for the fully open gate.

The headloss coefficient (K_g) at various gate openings can be determined from Figure B-12. Gate loss coefficients for both circular leaf and square bottom gates with gate openings from 10 to 100 percent are included on this figure. The circular leaf is found on light duty gates while most heavy duty gates have straight bottom. Entrance headloss coefficients (K_e) can be determined from Figure B-5. Friction headloss coefficients (K_p) for various pipe sizes to be combined with the pipe length can be determined from Figure B-13.

The conduit exit headloss is considered to be equal to the headloss at a sudden infinite enlargement. The exit headloss coefficient is, therefore, considered to equal 1.0. For special conditions such as bends (other than those illustrated), enlargements or contraction, and refinement in hydraulic analysis refer to NEH, Section 5, Hydraulics.

VII. REVIEW

Before going into the selection and detailing of appurtenances, the overall hydraulic picture of the outlet system should be reviewed.

Recognizing that some water level other than full reservoir may be the controlling head for selecting conduit size, has the critical water level been determined? The system capacity is affected by the individual head losses:

(1) configuration of the inlet whether re-entrant or flush,
(2) bend, whether single or multiple miter,
(3) effect of the vent pipe on the system head,
(4) type of pipe-corrugated metal, monolithic concrete, or cylinder pipe, etc., as it effects the hydraulic roughness coefficient,
(5) pipe diameter, whether it is a stock size and available locally,
(6) the outlet, whether submerged or discharging freely at atmospheric pressure, etc.

VIII. EXAMPLE PROBLEM

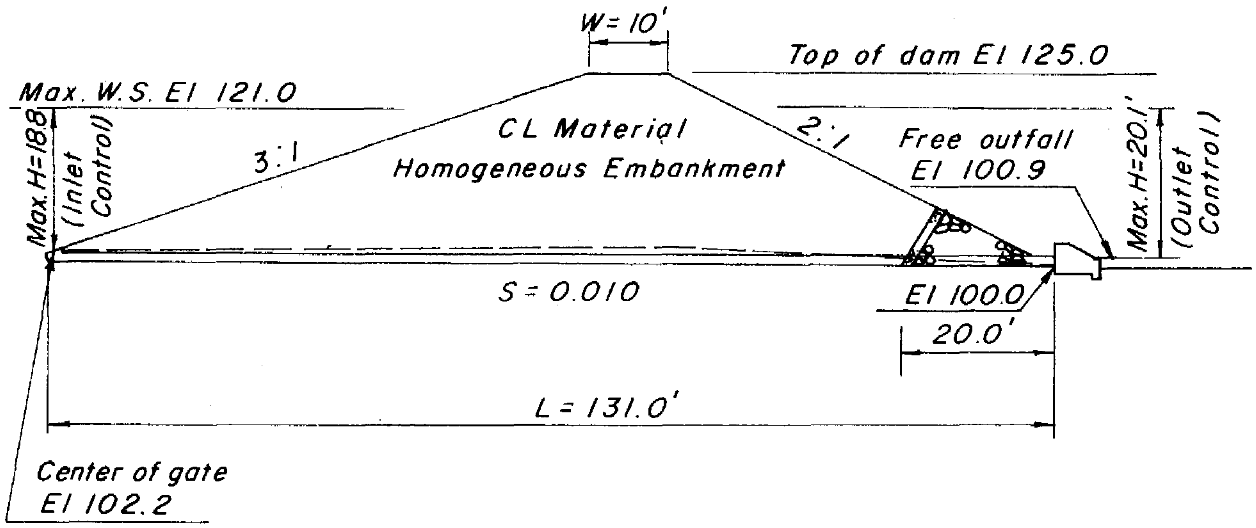
The following example deals with the hydraulic design of an outlet for a small earthfill dam. It is assumed that the height, slopes and top width of the dam are known and the elevation of the conduit inlet and outlet are given. It is also assumed that the discharge requirements for the outlet have been determined from hydrologic data and downstream flow requirements.

Given:

An earthfill dam with the height and slopes, as shown in the following sketch will require an outlet conduit to satisfy the following:

1. Discharge 40 cfs at maximum reservoir level
2. Discharge 20 cfs at intermediate levels.
3. Discharge 15 cfs as base flow with water level at El 110.0.

A square bottom slide gate is to be used.



Determine:

Select the conduit size and associated gate openings to satisfy the listed conditions.

Problem Analysis:

1. Determine Manning's roughness coefficient "n" for several types of conduits available, or to be considered.

2. Find conduit diameter required to carry required discharges for (a) full reservoir, and (b) partly empty reservoir.

3. Compare answer in 2 (a) and (b) above, determine critical condition and select conduit size.

4. Find gate opening required to limit discharge for noncritical head-conduit diameter relation.

5. Check availability of gate and conduit selected.

Solution:

1. Determine the diameters of several types of pipe to meet the discharge requirements (check local availability).

a. For maximum head maximum discharge, use Figures B-1 thru B-4. (These figures apply for the full reservoir condition.)

Enter each chart with Q = 40 cfs and H = 20 ft.

Find:	Steel pipe	(n = 0.011)	= 19.5", use 20" dia.
	Concrete pipe	(n = 0.013)	= 20.5", use 21" dia.
	CM pipe	(n = 0.024)	= 24" dia.

b. Find the diameter of pipe for 20 cfs at the minimum head. Figures B-5 thru B-10 should be used because the system head is less than that for full reservoir. These figures are entered with the following given data:

Entrance loss K_e = 1.24 from Figure B-5 or see diagram on appropriate Figures B-6 thru B-10.

Conduit length = 131 ft from problem sketch

Discharge Q = 20 cfs) Operation
Head H = 9 ft (El 110.0 - 100.9)) Requirements

Find:	Steel pipe	(n = 0.011)	= 17.7, use 18" dia.
	Concrete pipe	(n = 0.013)	= 18" dia.
	CM pipe	(n = 0.024)	= 21" dia.

2. From a comparison of the conduit diameters required for the two discharge conditions, it is obvious the critical discharge is for maximum head condition. To satisfy the site requirements, any one of the following will satisfy the discharge needs:

Steel pipe	20" diameter
Concrete pipe	21" "
CM pipe	24" "

Since the rest of the procedure is similar for all three pipe types, only the 21" diameter concrete pipe will be used to continue the example to completion.

3. Determine the gate opening to provide a discharge of 20 cfs with the reservoir at El 110.0.

For free outfall, the water surface at the outlet of the conduit is considered to be at the center of the pipe. The tailwater elevation for this example is, therefore, considered to be 100.9 ft. The head on the system with the reservoir at the permanent pool elevation is 110.00 - 100.9 = 9.1 ft. The head on the conduit inlet is 110.00 - 102.2 = 7.8 ft.

Check for full pipe flow to see if this condition controls the discharge in the system.

Enter Figure B-15 for n = 0.013 with D = 21" and S = 0.010. Find Q = 16 cfs. Therefore, the pipe will flow full at 20 cfs (operation requirements) and Figure B-12 applies. To reduce the discharge, the gate will have to be partially closed. Approximate gate closure can be determined from the rearranged discharge equation from page B-6.

$$\Sigma K = \left[\frac{6.30\ D^2 H^{1/2}}{Q}\right]^2$$

Substituting known values of D, H and Q

$$\Sigma K = \left[\frac{6.30(1.75)^2(9.12)^{1/2}}{20}\right]^2 = 8.5$$

Also, knowing the following headloss coefficients,

Pipe friction (n = 0.013, d = 21",
K_p = 0.0148) from Fig. B-13
$K_p \ell$ = (0.0148) 131 = 1.94
Bend, single miter (3:1 slope)
from Fig. B-5
K_b = 1.24 - 0.5 = 0.74
Outlet, K_o = 1.00
Gate, K_g = K_g

Then the $\Sigma K = K_p \ell + K_b + K_o + K_g = 3.68 + K_g$
and $K_g = \Sigma K - (K_p \ell + K_b + K_o) = 8.5 - 3.68 = 4.82$

Enter Figure B-12 with this value of K_g and assume a square bottom gate leaf, find approximate gate opening of 48% for the 20 cfs at a head of 9.1 ft.

4. Determine the gate opening to provide 15 cfs discharge with the reservoir level at El 121.0 and also at El 110.0.

The head on the conduit inlet with the reservoir level at the maximum elevation is 121.0 - 102.2 = 18.8 ft.

With the reservoir at El 110.0, the head on the conduit inlet is 110.0 - 102.2 = 7.8 ft.

From the previous check for full pipe flow, it was determined that the normal full pipe flow at the given slope was 16 cfs. The pipe would, therefore, flow partly full for a discharge of 15 cfs provided that the outlet was not submerged. Figure B-11 is then used to determine the gate opening.

Enter the nomography with H = 18.8 ft and extend a line through Q = 15 cfs to the pivot line. The diameter of 1.75 is connected to the point on the pivot line and extended to find C_v = 0.175. For a square bottom slide-gate the opening corresponding to C_v = 0.175 is approximately 32 percent of the diameter.

This setting would provide the required base flow discharge of 15 cfs when the reservoir level was at the maximum elevation.

For H = 7.8 ft, Q = 15 cfs, and D = 1.75 ft, C_v was determined to be 0.27. For a square bottom gate, the gate opening was determined to be approximately 43 percent. This setting will allow the required base flow (discharge) of 15 cfs when the reservoir level is at El 110.0.

5. The 21 in. diameter pipe satisfies the functional requirements. A quick check of a gate catalogue shows a 21 in. gate available as a stock item for the system head. In the event a conduit is selected for which a stock size gate is not available, the next larger gate will be used. A short transition cast-in-place in the inlet structure is recommended for this situation.

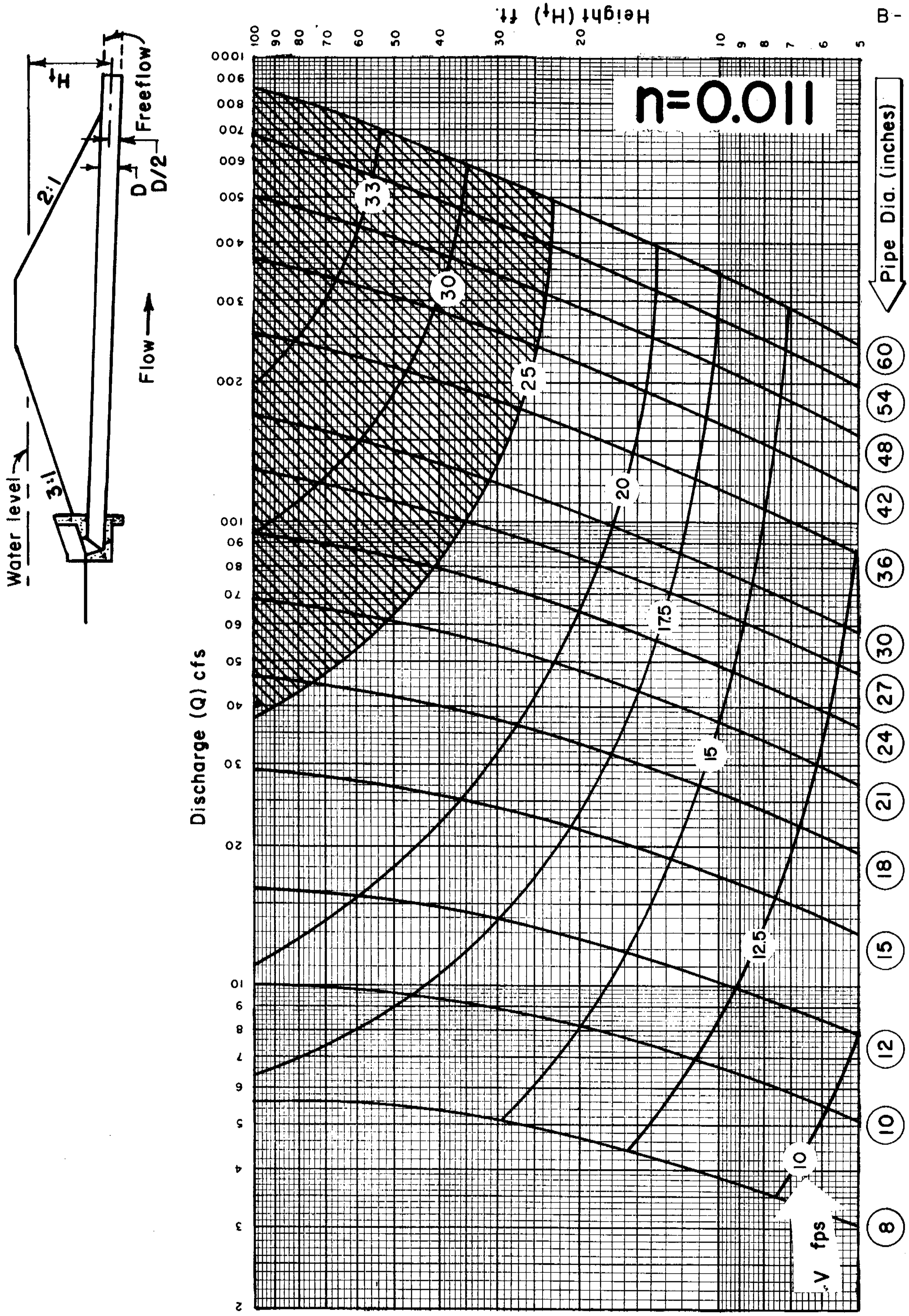


FIGURE B-1
FULL PIPE FLOW
STAGE DISCHARGE
EWP Unit Portland, Oregon

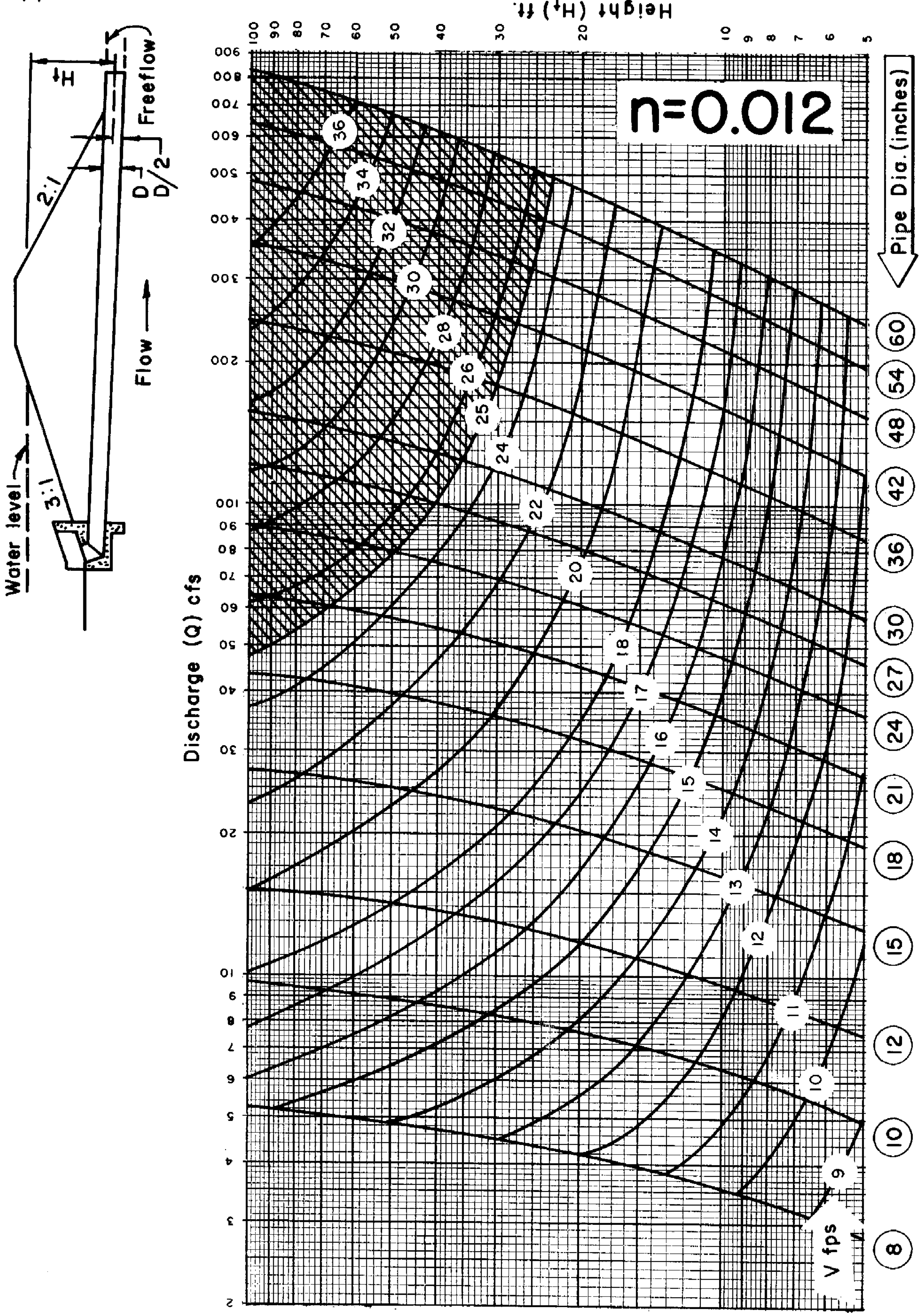


FIGURE B-2
FULL PIPE FLOW
STAGE DISCHARGE
EWP Unit Portland, Oregon

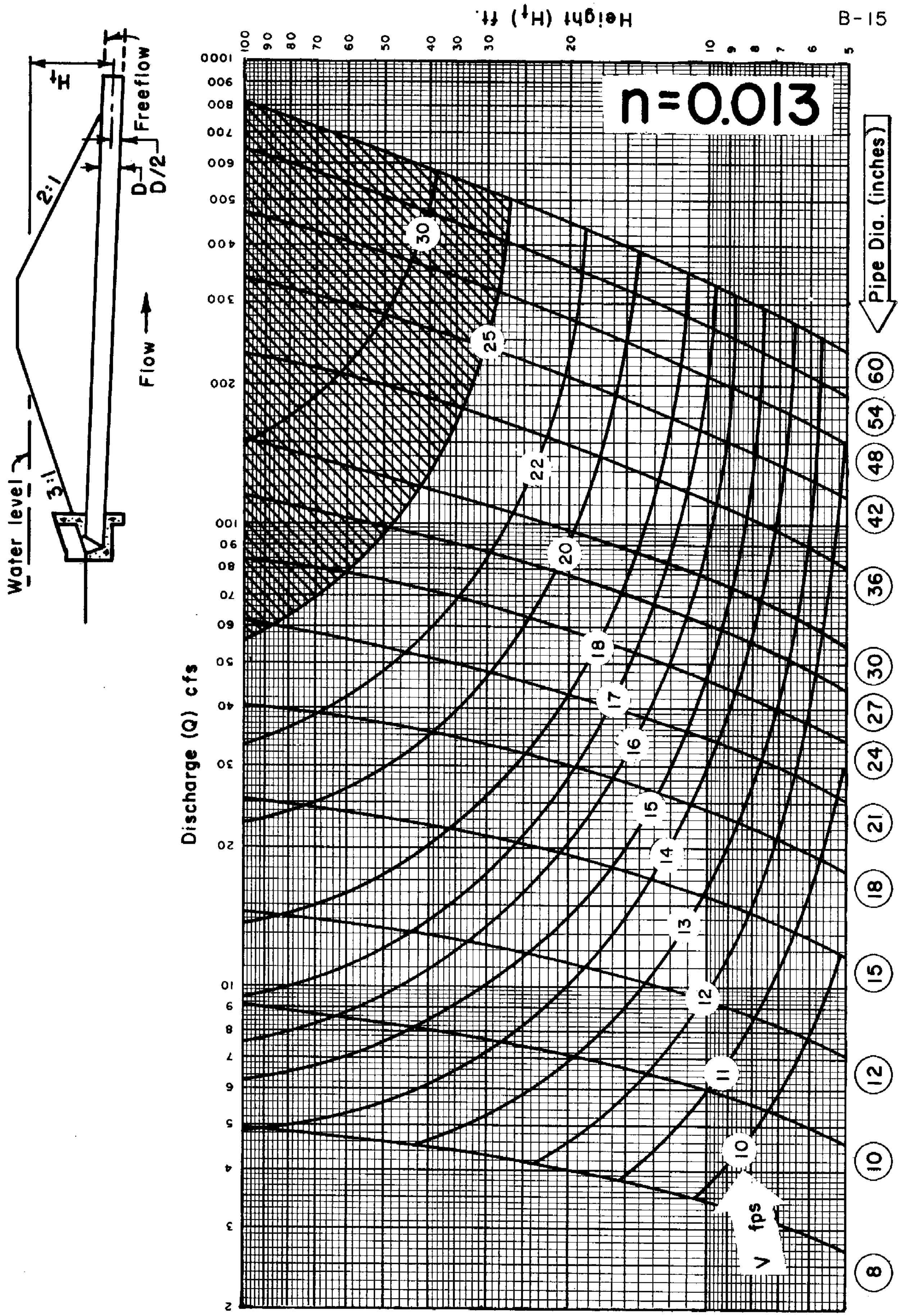


FIGURE B-3
FULL PIPE FLOW
STAGE DISCHARGE
EWP Unit Portland, Oregon

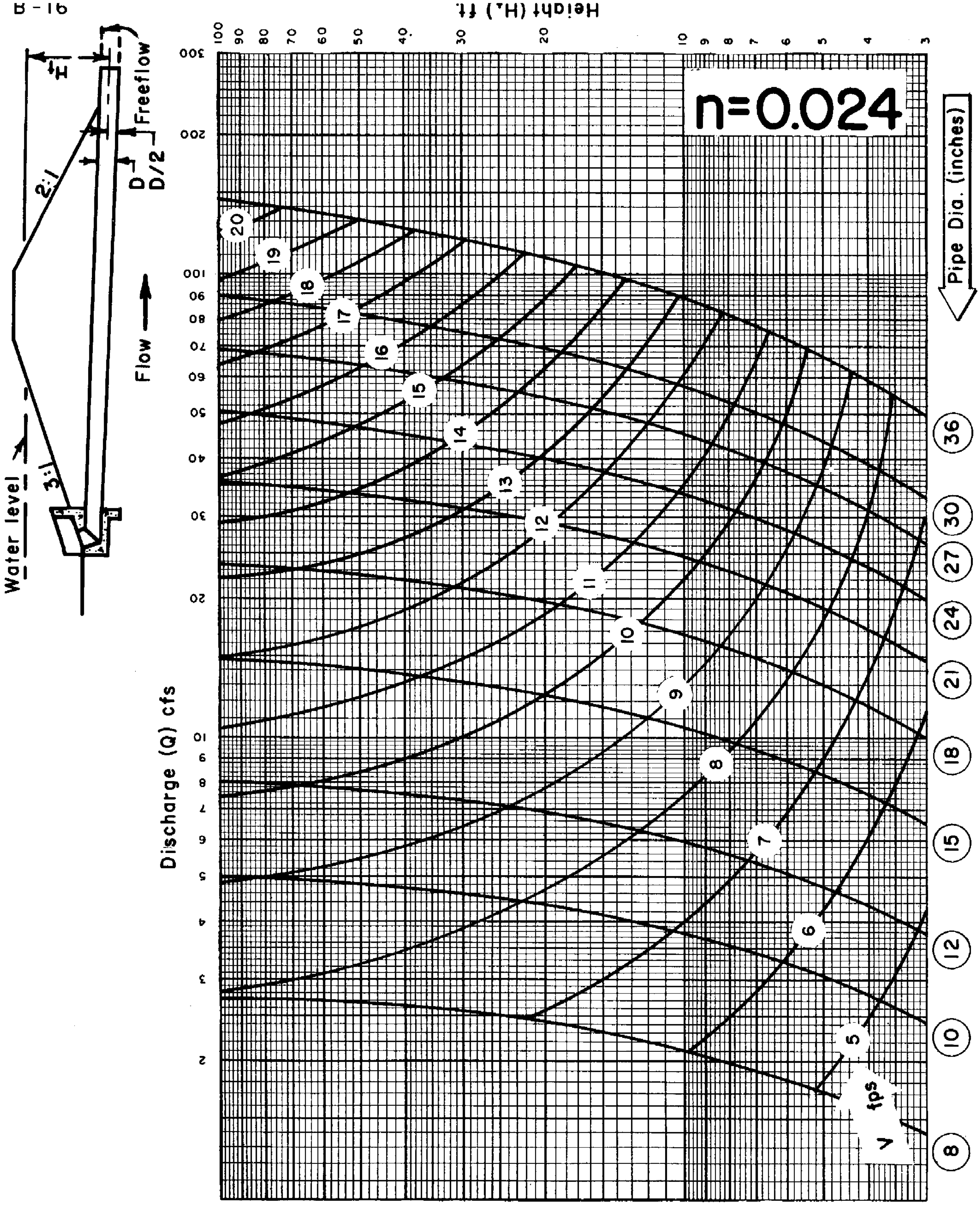
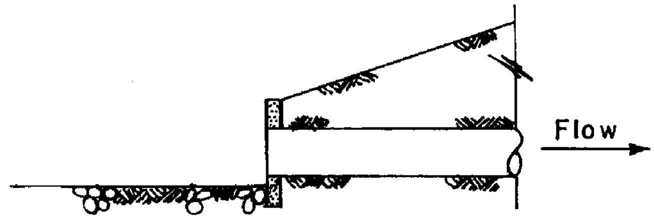


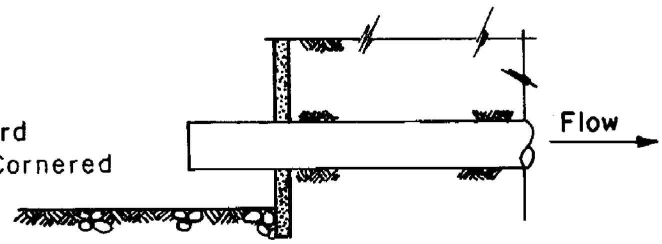
FIGURE B-4
FULL PIPE FLOW
STAGE DISCHARGE
EWP Unit Portland, Oregon

Straight Inlet
Square Cornered



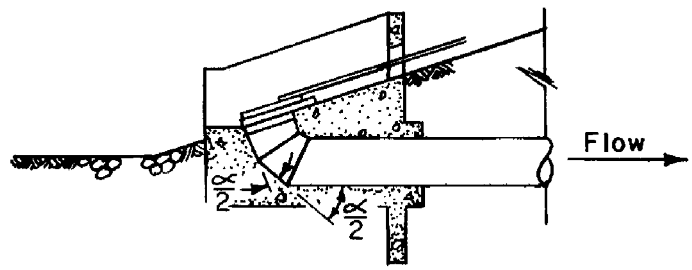
$K_e = 0.50$

Straight Inlet – Inward
Projecting – Square Cornered



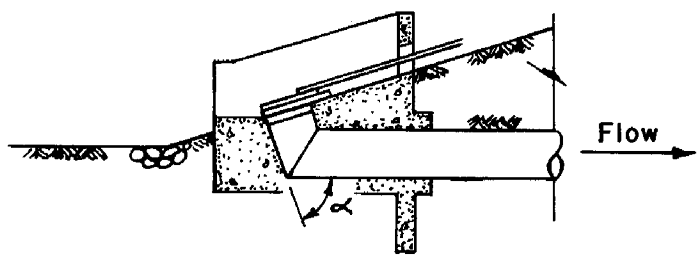
$K_e = 0.78$

Double Miter Bend
Square Corner



$K_e^* = 0.99$

Single Miter Bend
Square Corner



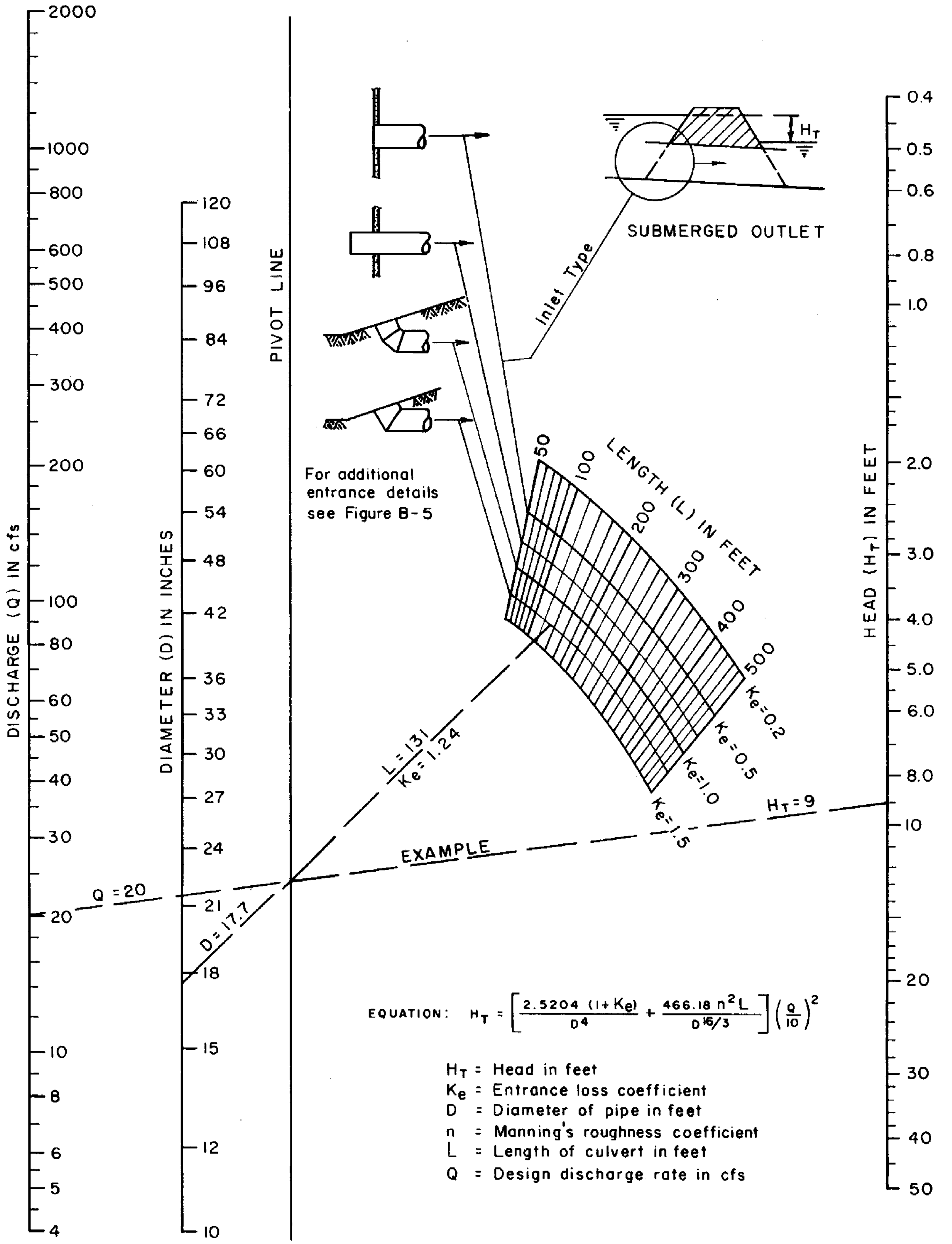
$K_e^* = 1.24$

SLOPE	α	K_e^* Single	K_e^* Double
2.5 : 1	69°	1.18	0.94
3 : 1	71°	1.20	0.98
3.5 : 1	74°	1.25	1.00
4 : 1	76°	1.29	1.02
	Ave.	1.24	0.99

K_e^* – Includes Bend Loss Coefficient
0.5 of the listed value is for the inlet, the remainder for the bend.
Trash rack losses are negligible for the standard inlet.

FIGURE B-5
FULL PIPE FLOW
ENTRANCE LOSS COEFFICIENT
EWP Unit Portland, Oregon

n = 0.011

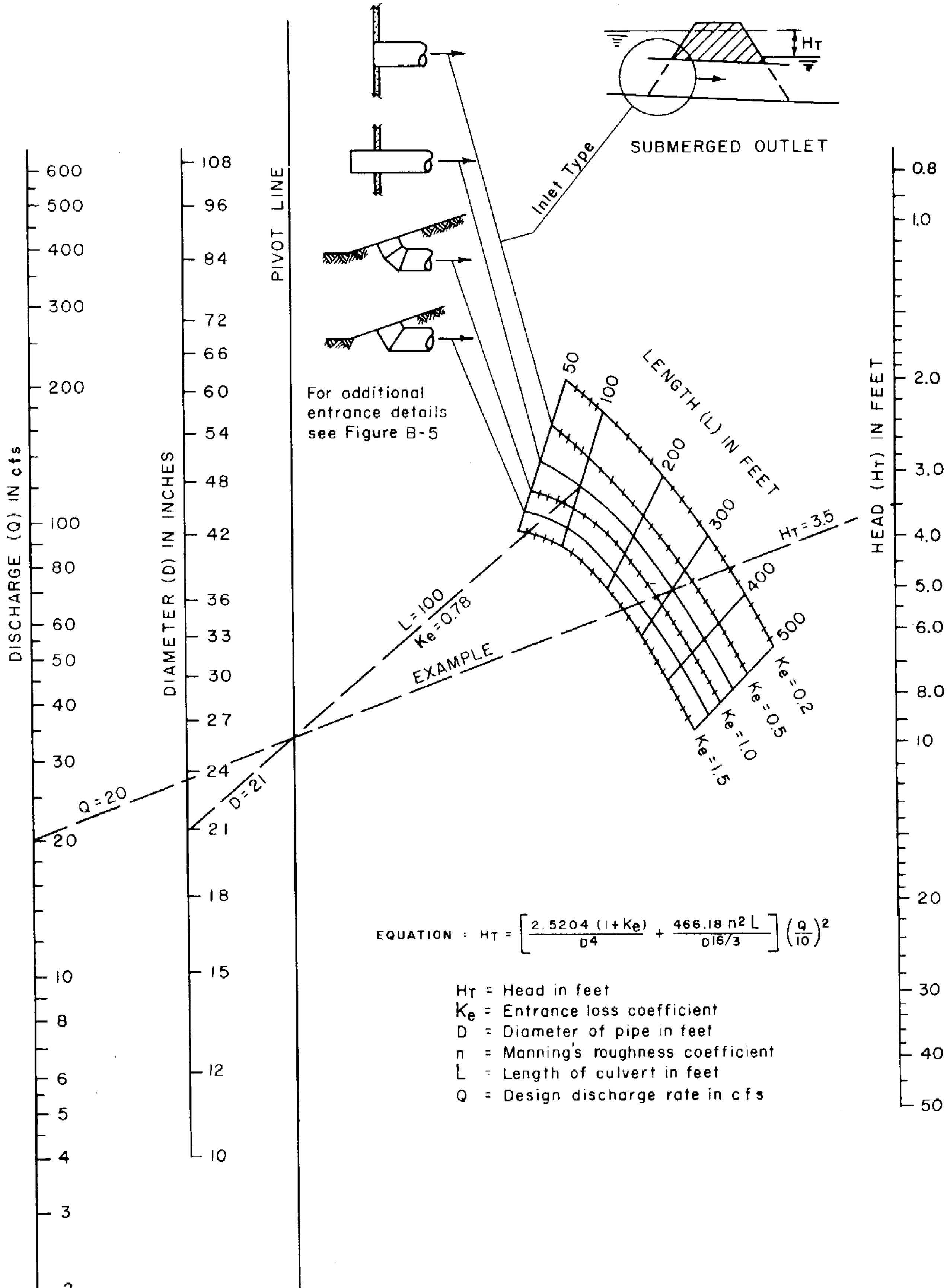


EQUATION: $H_T = \left[\frac{2.5204\ (1+K_e)}{D^4} + \frac{466.18\ n^2 L}{D^{16/3}}\right]\left(\frac{Q}{10}\right)^2$

H_T = Head in feet
K_e = Entrance loss coefficient
D = Diameter of pipe in feet
n = Manning's roughness coefficient
L = Length of culvert in feet
Q = Design discharge rate in cfs

REFERENCE
After Bureau of Public Roads Charts

FIGURE B-6
DISCHARGE FOR FULL PIPE FLOW n=0.011
EWP Unit Portland, Oregon



EQUATION : $H_T = \left[\frac{2.5204\,(1 + K_e)}{D^4} + \frac{466.18\, n^2 L}{D^{16/3}} \right] \left(\frac{Q}{10} \right)^2$

H_T = Head in feet
K_e = Entrance loss coefficient
D = Diameter of pipe in feet
n = Manning's roughness coefficient
L = Length of culvert in feet
Q = Design discharge rate in cfs

FIGURE B-7

DISCHARGE FOR FULL PIPE FLOW n = 0.012

EWP Unit Portland, Oregon

REFERENCE

After Bureau of Public Roads Charts

n = 0.012

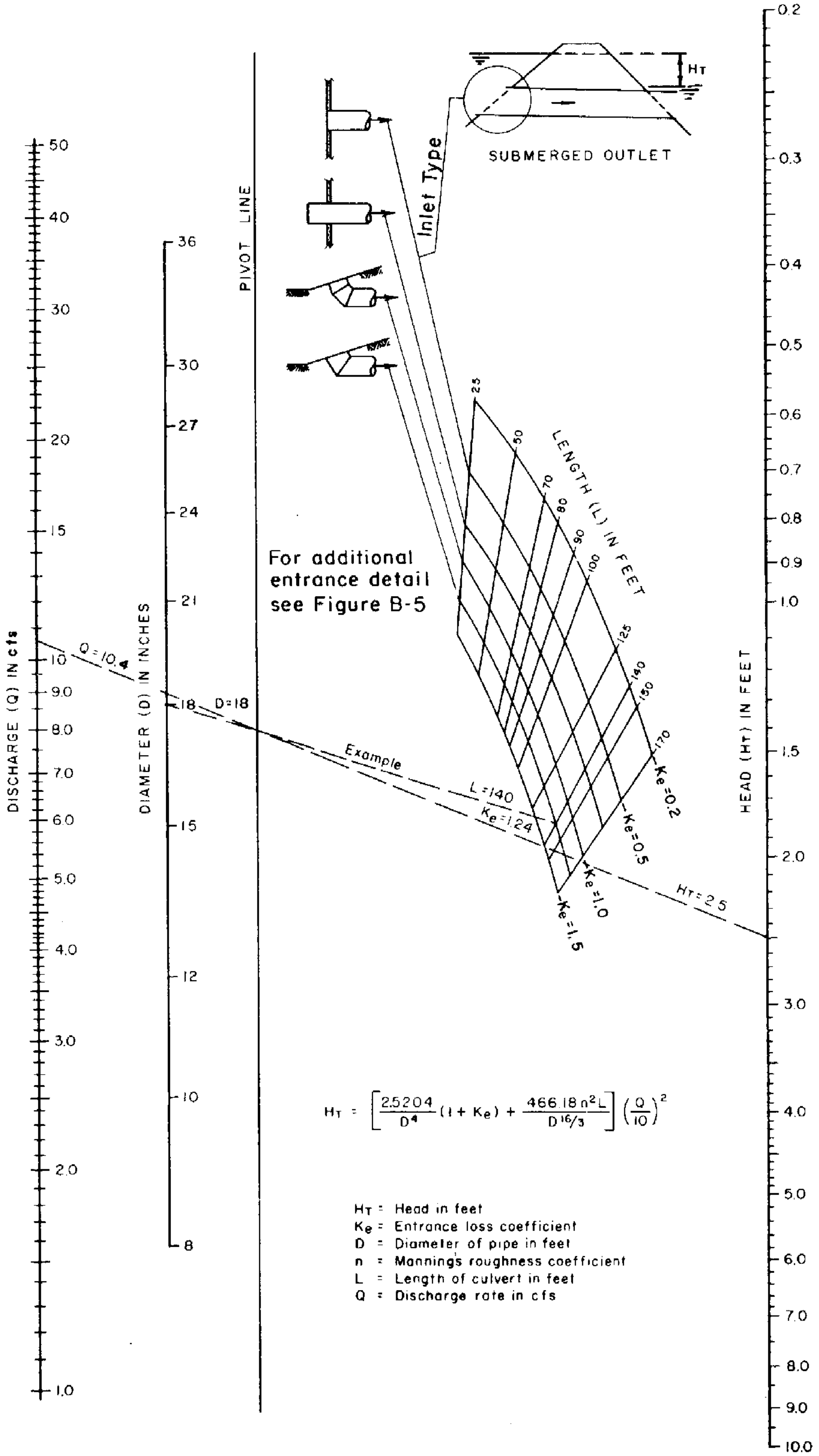


FIGURE B-8

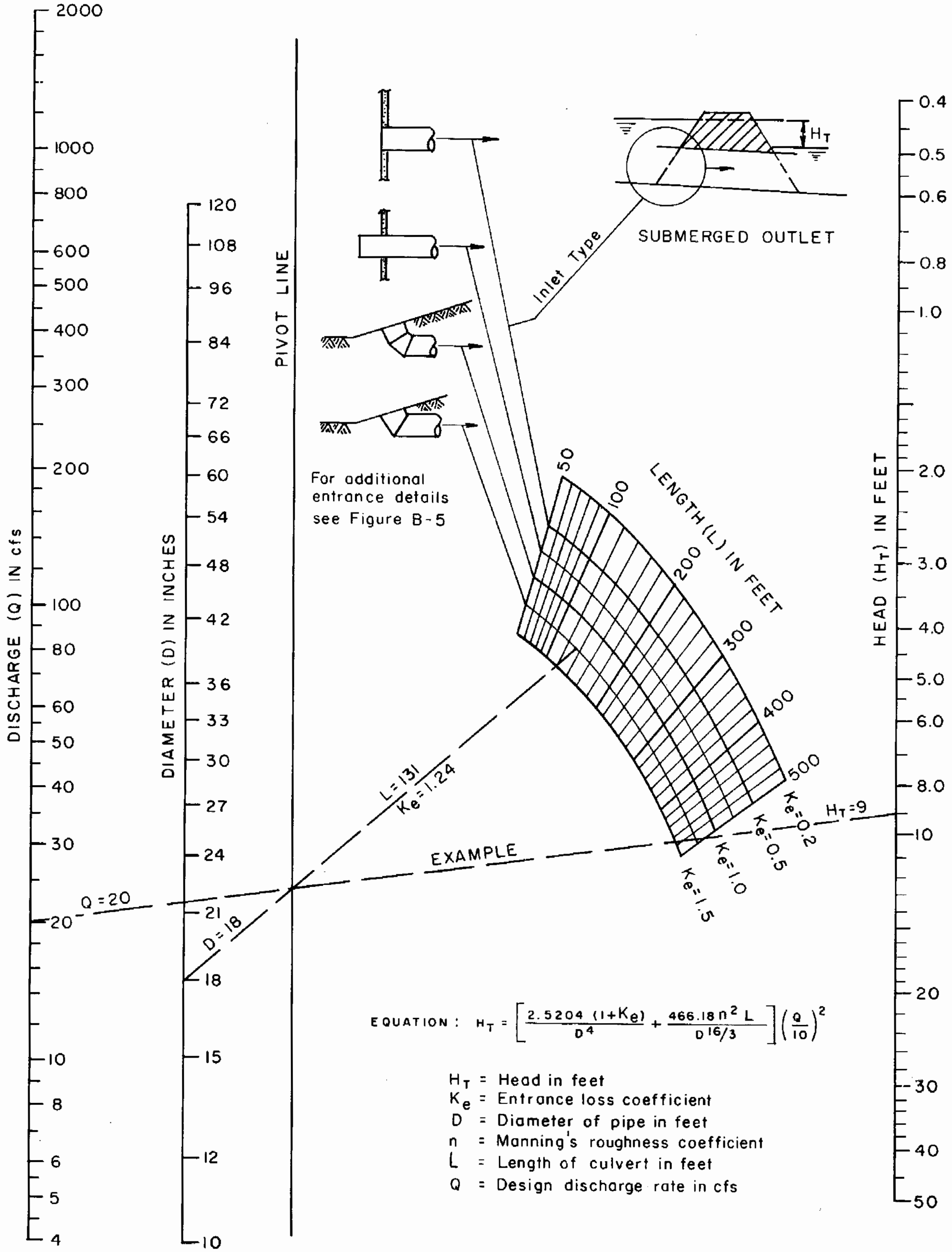
DISCHARGE FOR FULL PIPE FLOW n=0.012

EWP Unit Portland, Oregon

REFERENCE

After Bureau of Public Roads Charts.

n = 0.013



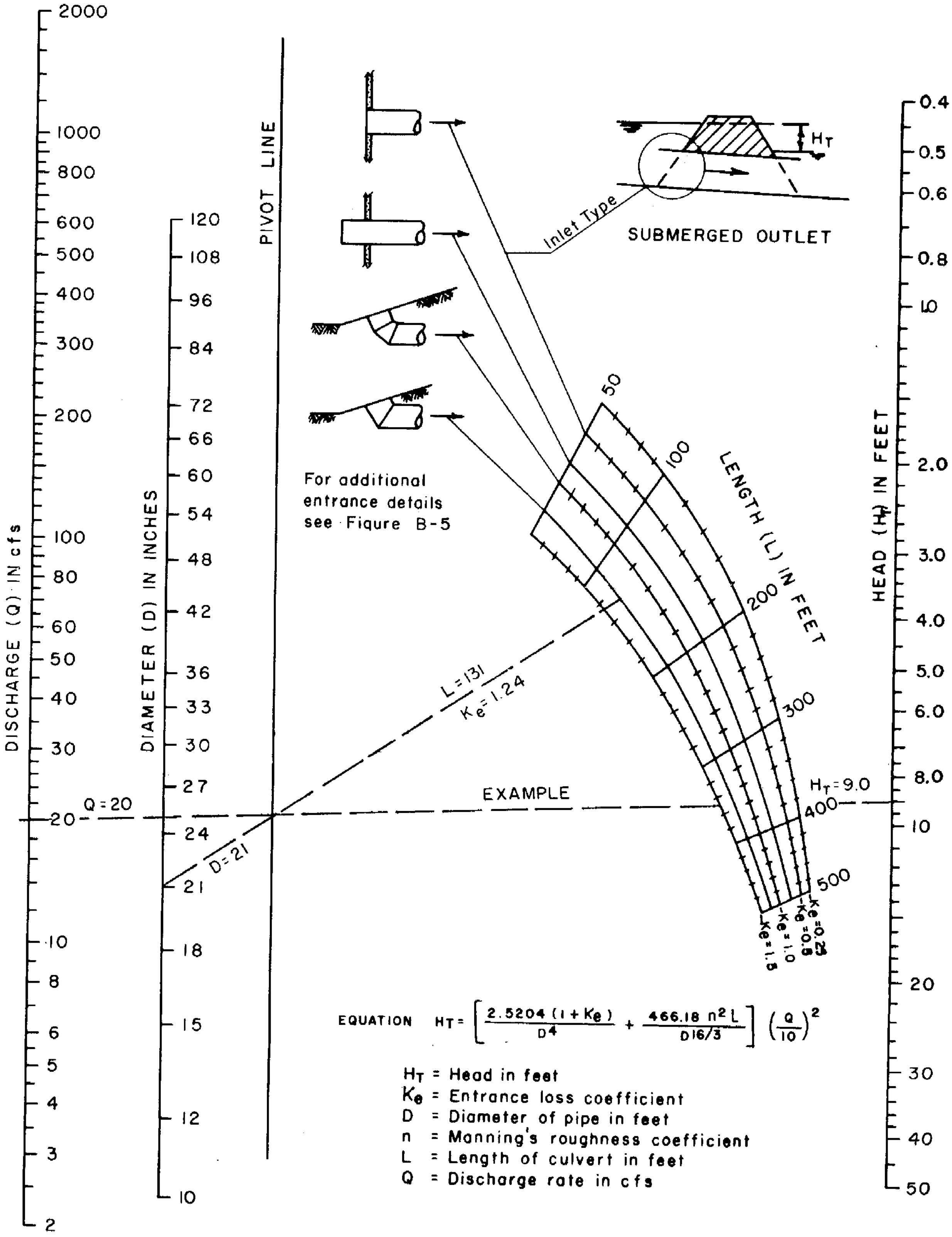
EQUATION : $H_T = \left[\frac{2.5204\,(1+K_e)}{D^4} + \frac{466.18\,n^2\,L}{D^{16/3}}\right]\left(\frac{Q}{10}\right)^2$

H_T = Head in feet
K_e = Entrance loss coefficient
D = Diameter of pipe in feet
n = Manning's roughness coefficient
L = Length of culvert in feet
Q = Design discharge rate in cfs

REFERENCE
After Bureau of Public Roads Charts

FIGURE B-9
DISCHARGE FOR FULL PIPE FLOW n=0.013
EWP Unit Portland, Oregon

n=0.024



EQUATION $$H_T = \left[\frac{2.5204\,(1+K_e)}{D^4} + \frac{466.18\,n^2 L}{D^{16/3}}\right]\left(\frac{Q}{10}\right)^2$$

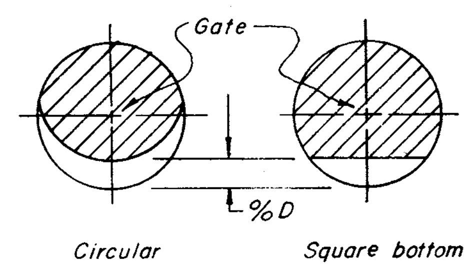
H_T = Head in feet
K_e = Entrance loss coefficient
D = Diameter of pipe in feet
n = Manning's roughness coefficient
L = Length of culvert in feet
Q = Discharge rate in cfs

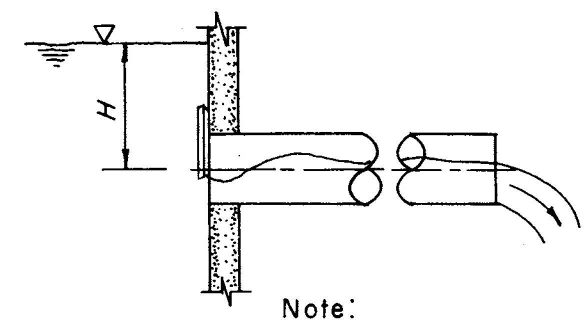
REFERENCE
After Bureau of Public Roads Charts

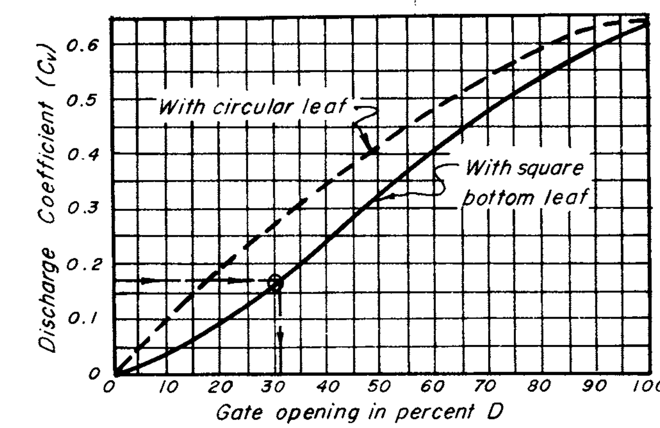
FIGURE B-10

DISCHARGE FOR FULL PIPE FLOW n=0.024

EWP Unit Portland, Oregon



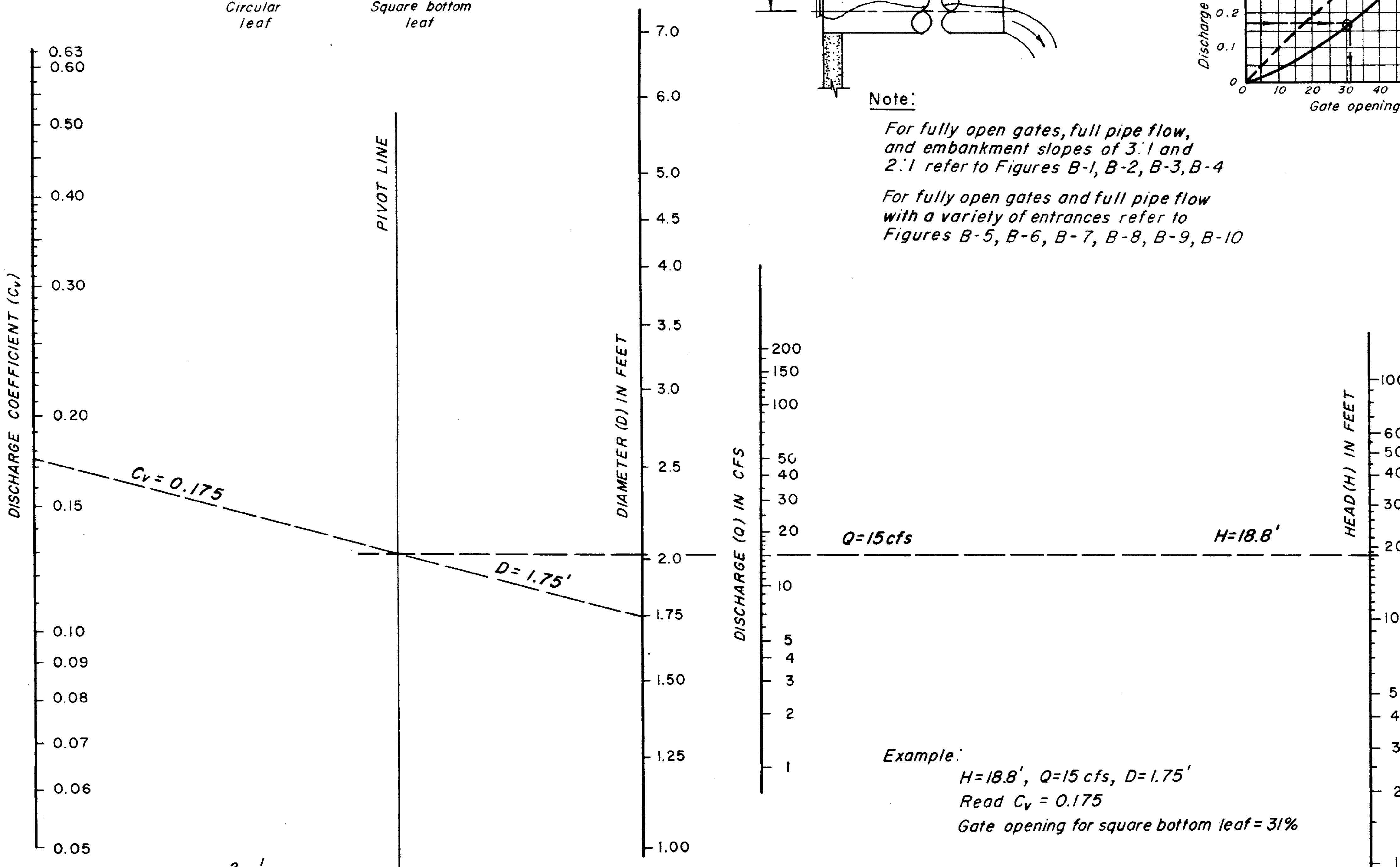




Note:

For fully open gates, full pipe flow, and embankment slopes of 3:1 and 2:1 refer to Figures B-1, B-2, B-3, B-4

For fully open gates and full pipe flow with a variety of entrances refer to Figures B-5, B-6, B-7, B-8, B-9, B-10



Example:

$H = 18.8'$, $Q = 15$ cfs, $D = 1.75'$

Read $C_v = 0.175$

Gate opening for square bottom leaf = 31%

$$Q = 6.32\, C_v D^2 H^{\frac{1}{2}}$$

Q = Design discharge rate in cfs

C_v = Gate discharge coefficient

D = Diameter of pipe in feet

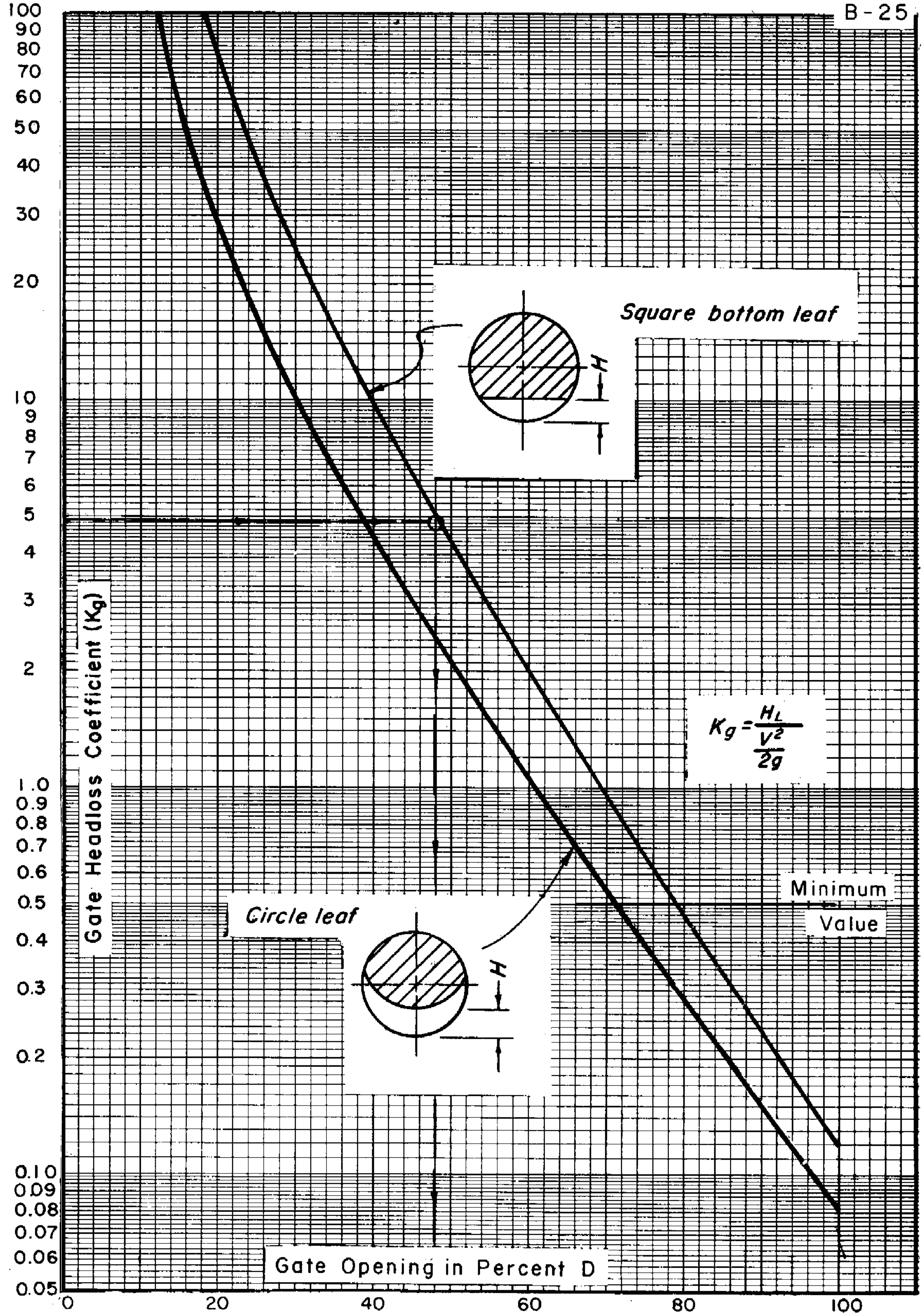
H = Head in feet measured to center line of conduit

REFERENCE: Ball, J. W., "Limitations of Metergates," ASCE Journal of Irrigation and Drainage, Dec. 1962, p. 26, paper No. 3359.

FIGURE B-11

FREE DISCHARGE THRU PARTIALLY OPEN GATES

EWP Unit Portland, Oregon



REFERENCE:
W.E.S. Hyd. Chart 330-1

FIGURE B-12

GATE HEADLOSS COEFFICIENT (K_g) FULL PIPE FLOW

EWP Unit Portland, Oregon

HEAD LOSS COEFFICIENT, K_p, FOR CIRCULAR PIPE FLOWING FULL $K_p = \frac{5087\,n^2}{D^{4/3}}$

Pipe diam. inches	Flow area sq. ft.	MANNING'S COEFFICIENT OF ROUGHNESS "n" 0.010	0.011	0.012	0.013	0.014	0.015	0.016	0.017	0.018	0.019	0.020	0.021	0.022	0.023	0.024	0.025
6	0.196	0.0467	0.0565	0.0672	0.0789	0.0914	0.1050	0.1194	0.1348	0.151	0.168	0.187	0.206	0.226	0.247	0.269	0.292
8	0.349	.0318	.0385	.0458	.0537	.0623	.0715	.0814	.0919	.1030	.1148	.1272	.140	.154	.168	.183	.199
10	0.545	.0236	.0286	.0340	.0399	.0463	.0531	.0604	.0682	.0765	.0852	.0944	.1041	.1143	.1249	.136	.148
12	0.785	.0185	.0224	.0267	.0313	.0363	.0417	.0474	.0535	.0600	.0668	.0741	.0817	.0896	.0980	.1067	.1157
14	1.069	.0151	.0182	.0217	.0255	.0295	.0339	.0386	.0436	.0488	.0544	.0603	.0665	.0730	.0798	.0868	.0942
15	1.23	.0138	.0166	.0198	.0232	.0270	.0309	.0352	.0397	.0446	.0496	.0550	.0606	.0666	.0727	.0792	.0859
16	1.40	.0126	.0153	.0182	.0213	.0247	.0284	.0323	.0365	.0409	.0455	.0505	.0556	.0611	.0667	.0727	.0789
18	1.77	.01078	.0130	.0155	.0182	.0211	.0243	.0276	.0312	.0349	.0389	.0431	.0476	.0522	.0570	.0621	.0674
21	2.41	.00878	.01062	.0126	.0148	.0172	.0198	.0225	.0254	.0284	.0317	.0351	.0387	.0425	.0464	.0506	.0549
24	3.14	.00735	.00889	.01058	.0124	.0144	.0165	.0188	.0212	.0238	.0265	.0294	.0324	.0356	.0389	.0423	.0459
27	3.98	.00628	.00760	.00904	.01061	.0123	.0141	.0161	.0181	.0203	.0227	.0251	.0277	.0304	.0332	.0362	.0393
30	4.91	.00546	.00660	.00786	.00922	.01070	.01228	.0140	.0158	.0177	.0197	.0218	.0241	.0264	.0289	.0314	.0341
36	7.07	.00428	.00518	.00616	.00723	.00839	.00963	.01096	.0124	.0139	.0154	.0171	.0189	.0207	.0226	.0246	.0267
42	9.62	.00348	.00422	.00502	.00589	.00683	.00761	.00892	.01007	.01129	.0126	.0139	.0154	.0169	.0184	.0201	.0218
48	12.57	.00292	.00353	.00420	.00493	.00572	.00656	.00747	.00843	.00945	.01053	.01166	.0129	.0141	.0154	.0168	.0182
54	15.90	.00249	.00302	.00359	.00421	.00488	.00561	.00638	.00720	.00808	.00900	.00997	.01099	.0121	.0132	.0144	.0156
60	19.63	.00217	.00262	.00312	.00366	.00424	.00487	.00554	.00626	.00702	.00782	.00866	.00955	.01048	.0115	.0125	.0135

HEAD LOSS COEFFICIENT, K_c, FOR SQUARE CONDUIT FLOWING FULL $K_c = \frac{29.16\,n^2}{r^{4/3}}$

Conduit Size feet	Flow area sq. ft.	MANNING'S COEFFICIENT OF ROUGHNESS "n" 0.012	0.013	0.014	0.015	0.016
2×2	4.00	0.01058	0.01242	0.01440	0.01653	0.01880
$2\frac{1}{2}\times2\frac{1}{2}$	6.25	0.00786	0.00922	0.01070	0.01228	0.01397
3×3	9.00	.00616	.00723	.00839	.00963	.01096
$3\frac{1}{2}\times3\frac{1}{2}$	12.25	.00502	.00589	.00683	.00784	.00892
4×4	16.00	.00420	.00493	.00572	.00656	.00746
$4\frac{1}{2}\times4\frac{1}{2}$	20.25	.00359	.00421	.00488	.00561	.00638
5×5	25.00	.00312	.00366	.00425	.00487	.00554
$5\frac{1}{2}\times5\frac{1}{2}$	30.25	.00275	.00322	.00374	.00429	.00488
6×6	36.00	.00245	.00287	.00333	.00382	.00435
$6\frac{1}{2}\times6\frac{1}{2}$	42.25	.00220	.00258	.00299	.00343	.00391
7×7	49.00	.00199	.00234	.00271	.00311	.00354
$7\frac{1}{2}\times7\frac{1}{2}$	56.25	.00182	.00213	.00247	.00284	.00323
8×8	64.00	.00167	.00196	.00227	.00260	.00296
$8\frac{1}{2}\times8\frac{1}{2}$	72.25	.00154	.00180	.00209	.00240	.00273
9×9	81.00	.00142	.00167	.00194	.00223	.00253
$9\frac{1}{2}\times9\frac{1}{2}$	90.25	.00133	.00156	.00180	.00207	.00236
10×10	100.00	.00124	.00145	.00168	.00193	.00220

$$H_l = (K_p \text{ or } K_c)\, L\, \frac{v^2}{2g}$$

<u>Nomenclature:</u>

- a = Cross-sectional area of flow in sq. ft.
- D = Inside diameter of pipe in inches.
- g = Acceleration of gravity = 32.2 ft. per sec.
- H_l = Loss of head in feet due to friction in length L.
- K_c = Head loss coefficient for square conduit flowing full.
- K_p = Head loss coefficient for circular pipe flowing full.
- L = Length of conduit in feet.
- n = Manning's coefficient of roughness.
- Q = Discharge or capacity in cu. ft. per sec.
- r = Hydraulic radius in feet.
- v = Mean velocity in ft. per sec.

<u>Example 1</u>: Compute the head loss in 300 ft. of 24 in. diam. concrete pipe flowing full and discharging 30 c.f.s. Assume $n = 0.015$

$$v = \frac{Q}{D} = \frac{30}{3.14} = 9.55 \text{ f.p.s.};\quad \frac{v^2}{2g} = \frac{(9.55)^2}{64.4} = 1.42 \text{ ft.}$$

$$H_l = K_p L \frac{v^2}{2g} = 0.0165 \times 300 \times 1.42 = 7.03 \text{ ft.}$$

<u>Example 2</u>: Compute the discharge of a 250 ft., 3×3 square conduit flowing full if the loss of head is determined to be 2.25 ft. Assume $n = 0.014$.

$$H_l = K_c L \frac{v^2}{2g};\quad \frac{v^2}{2g} = \frac{H_l}{K_c L} = \frac{2.25}{0.00839 \times 250} = 1.073 \text{ ft.}$$

$$v = \sqrt{64.4 \times 1.073} = 8.31;\quad Q = 9 \times 8.31 = 74.8 \text{ c f s.}$$

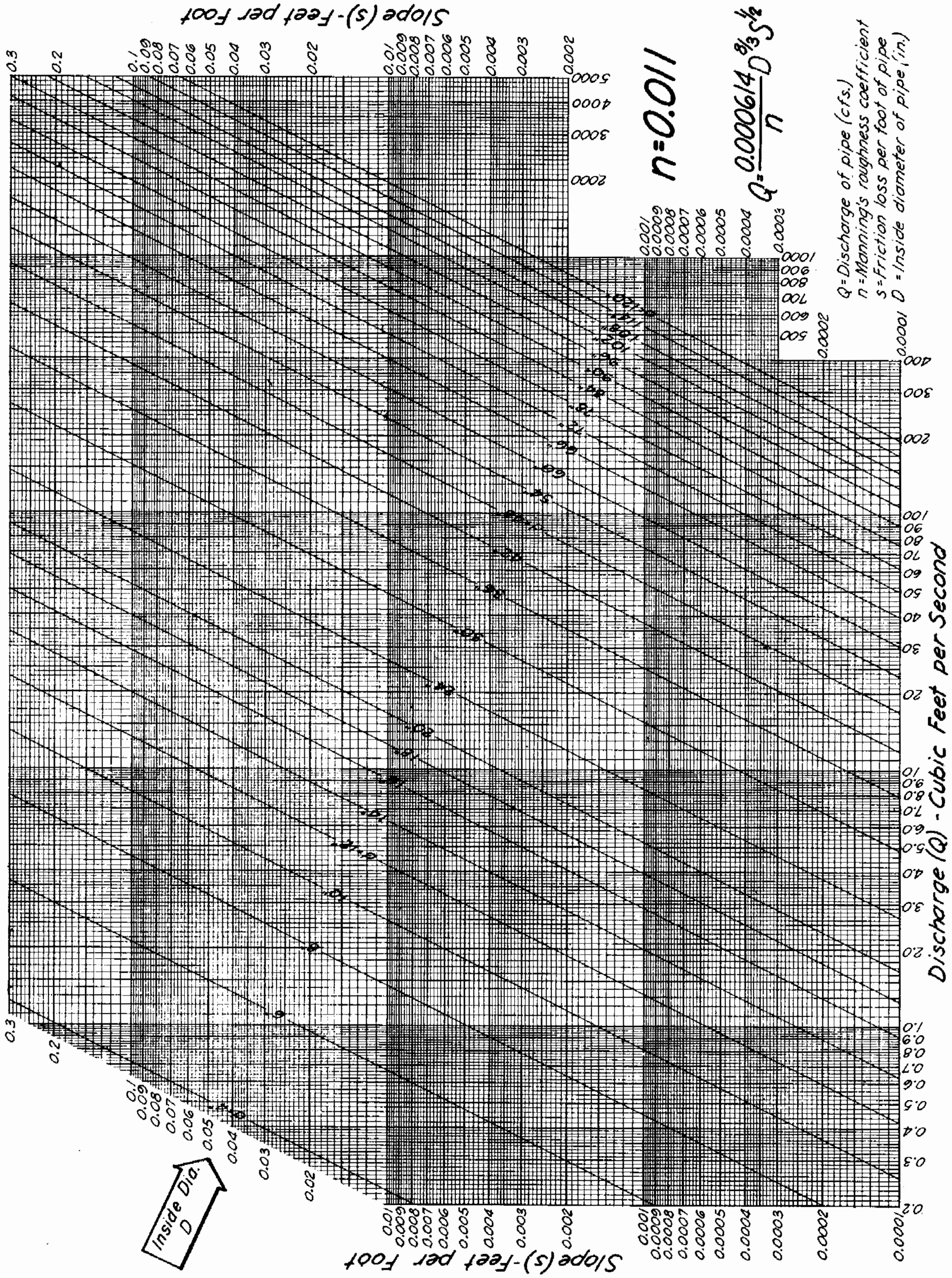
FIGURE B-13

HEAD LOSS COEFFICIENTS FOR CIRCULAR AND SQUARE CONDUITS FLOWING FULL

EWP Unit Portland, Oregon

REFERENCE:
ES - 42

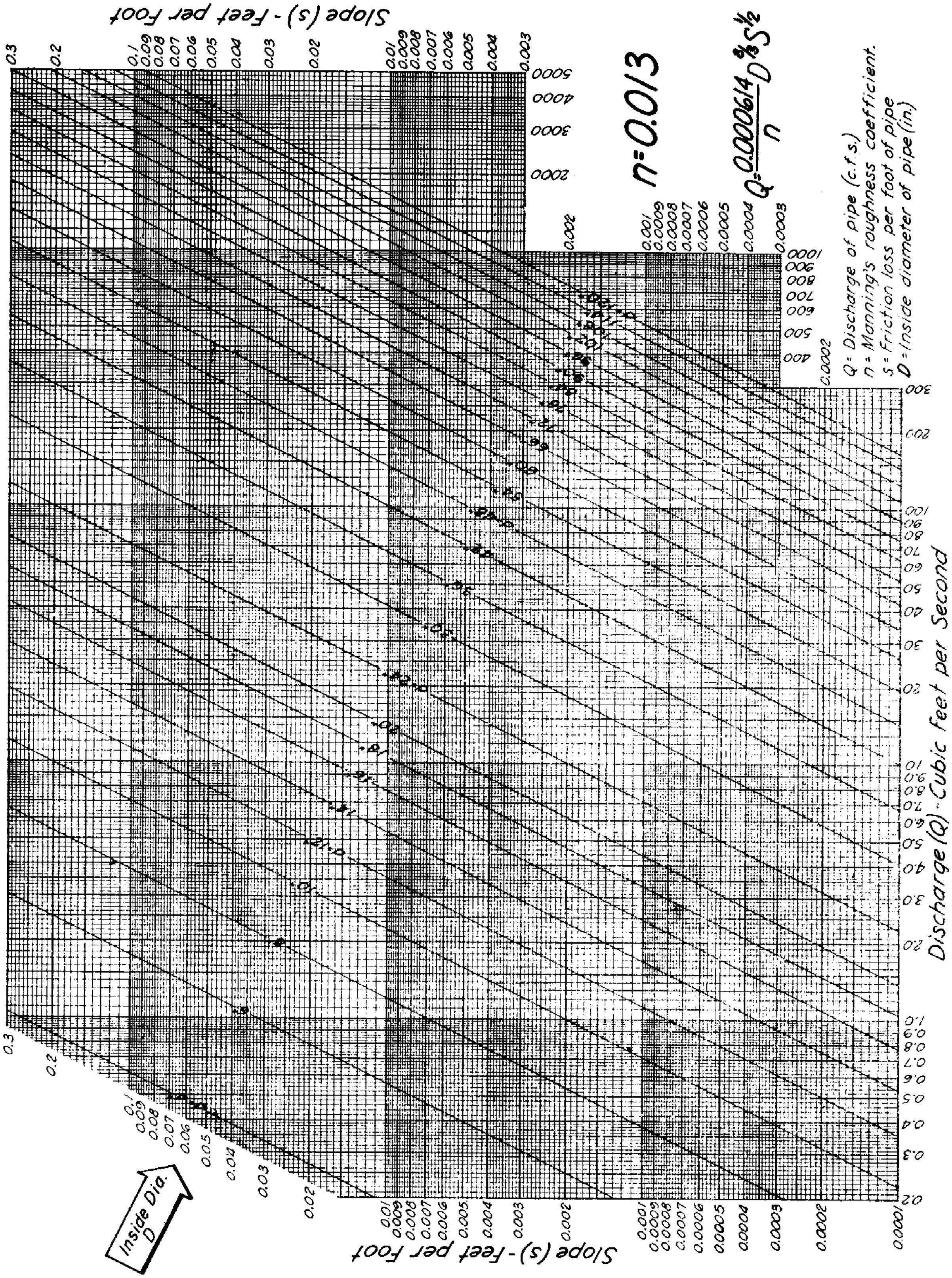
n=0.011



REFERENCE:
ES-54

FIGURE B-14
DISCHARGE OF CIRCULAR PIPE FLOWING FULL
EWP Unit Portland, Oregon

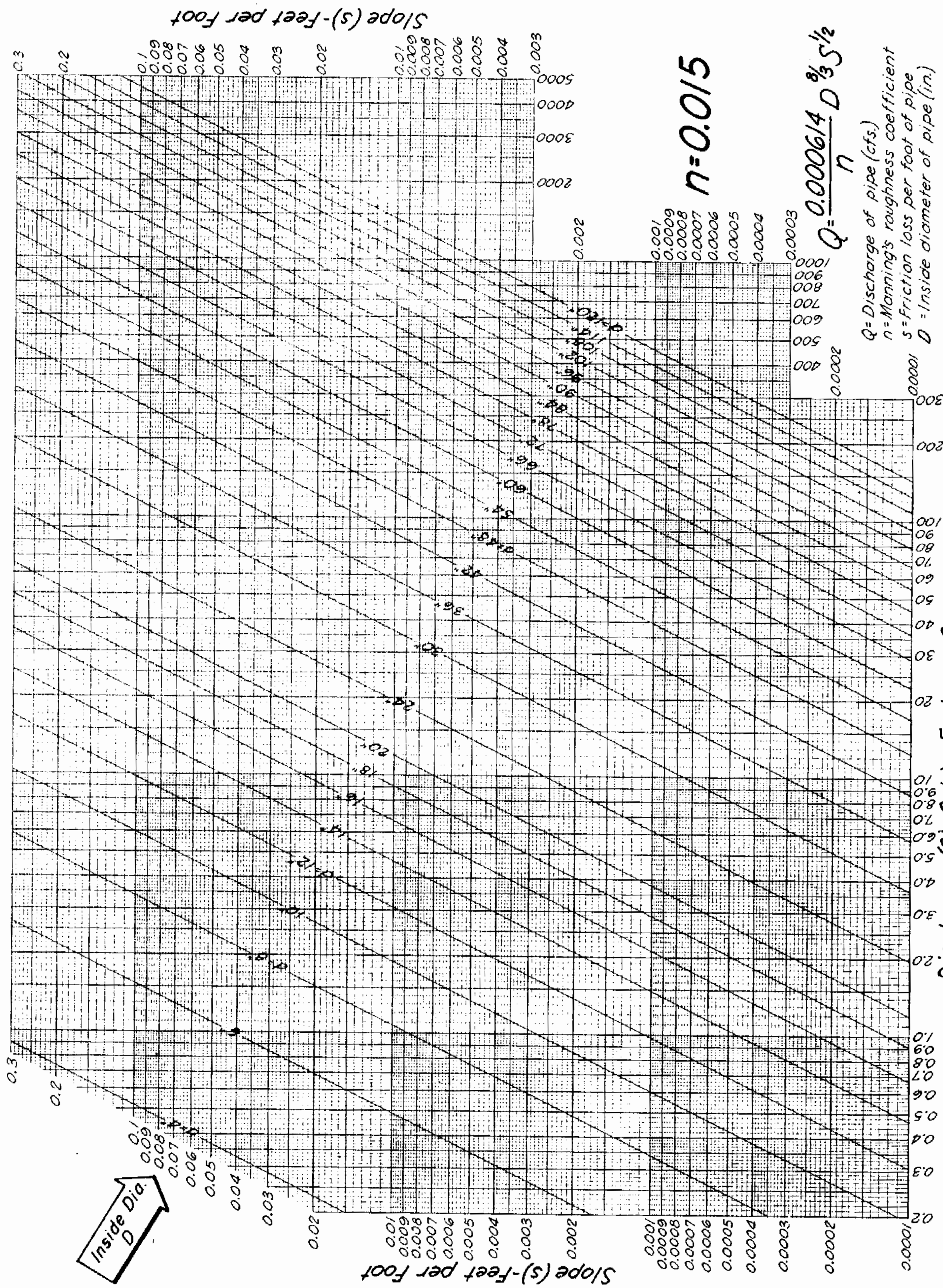
n=0.013



REFERENCE:
ES-54

FIGURE B-15
DISCHARGE OF CIRCULAR PIPE FLOWING FULL
EWP Unit Portland, Oregon

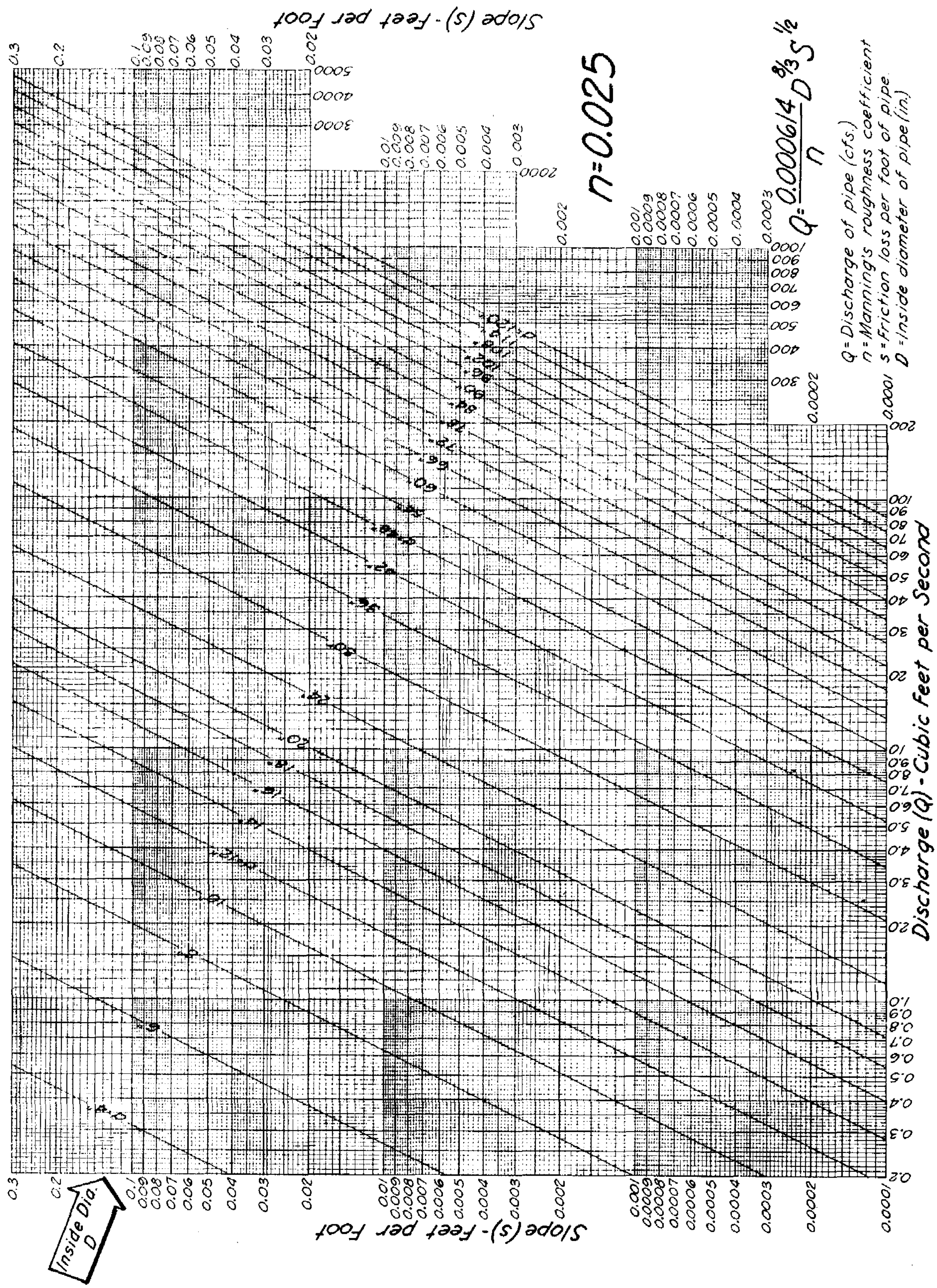
n=0.015



REFERENCE:
ES-54

FIGURE B-16
DISCHARGE OF CIRCULAR PIPE FLOWING FULL
EWP Unit Portland, Oregon

n=0.025



REFERENCE:
ES-54

FIGURE B-17
DISCHARGE OF CIRCULAR PIPE FLOWING FULL
EWP Unit Portland, Oregon